

10/585723

12/07/2006 PCT/PTO 12 JUL 2006

**COURTESY COPY OF THE
PCT APPLICATION AS
ORIGINALLY FILED
WITH ABSTRACT**

LENS ACTUATOR ASSEMBLY FOR OPTICAL HEAD

FIELD OF THE INVENTION

This invention relates to lens actuator assemblies, and in particular to such assemblies that allow tight focusing of a beam of electromagnetic radiation while recording/reading information at a plurality of locations in a three-dimensional optically scannable information carrier.

BACKGROUND OF THE INVENTION

Three-dimensional optical memory devices or information carriers have been developed being aimed at significantly increasing the amount of recordable data, as compared with conventional two-dimensional devices (typically two data-layer containing structures). Optical storage devices have customarily been dependent on the ability to focus a laser beam to a tight spot of the order of its diffraction limit so as to allow for squeezing as much information as possible onto the surface of the storage device. This requires correction for optical aberrations.

The inventors have found that correcting spherical aberrations over a predefined thickness of a specific material for specific wavelengths may be achieved by using only two separate optical assemblies - a first, main lens assembly that performs the majority of the light bending required for the focusing of light, and a second auxiliary lens assembly (corrector) that mainly compensates for the changing spherical aberration introduced by the changing of the thickness into which the light is being focused. Generally, aberration types that can be corrected are those induced by light traversing through varying depth within the disk material and include for example spherical aberrations

In US 5,712,842, an optical head is described having an objective lens mounted on a first holder and comprising a first actuator for moving the lens along the optical axis. A solid immersion lens, for the purpose of providing a large numerical aperture, is arranged between the objective lens and the

information carrier to be scanned, and mounted onto a second lens holder which is in turn mounted onto the first holder. The objective lens and the solid immersion lens are jointly moved parallel to the optical axis by means of the first actuator so that the scanning spot may be focused on the information layer of the

5 information carrier. A second actuator, axially displaced along the optical axis from the first actuator, is provided for enabling movement of the second lens holder and solid immersion lens independent of the movement of the objective lens, so that the spherical aberration of the radiation beam in the transparent protective layer of the information carrier present between the information layer

10 and the scanning device may be corrected. Thus, the objective lens focuses a radiation beam onto the information carrier, while the solid immersion lens enables the scanning device to have a large numerical aperture and thus scan information carriers having relatively small elementary information characteristics, i.e., high information density.

15 In US 6,310,840, a similar system to that of US 5,712,842 provides a large numerical aperture, but in US 6,310,840 the arrangement of the actuators is reversed with respect to that of US 5,712,842. Thus, in US 6,310,840, the objective lens holder is mounted with respect to the solid immersion lens holder, and the combination is actuated by the first actuator. A second actuator enables

20 the objective lens holder to be displaced with respect to the solid immersion lens holder. Thus, the necessary power required to operate the first actuator is considerably reduced.

In both references, the auxiliary lens has a planar side facing the optical carrier, and a highly convex side facing the main lens, and the auxiliary lens is

25 provided for the purpose of increasing the numerical aperture of the lens system. None of these references is concerned with focusing the radiation beam with respect to any one of a plurality of information layers within a three-dimensional information carrier.

SUMMARY OF THE INVENTION

In operation, the lens actuator assembly thus comprises two lens assemblies accommodated in an optical path of the exciting and excited light beams and being arranged in a spaced-apart relationship along an optical axis of the optical module

5 arrangement. According to the present invention, one of these two lens assemblies is designed to perform the majority of light bending required for the focusing of the exciting light and collecting the excited light, and the other lens assembly is designed to compensate for changing spherical aberration introduced by a change in a thickness of the medium into which the exciting light is being focused. The lenses

10 of the focusing/collecting arrangement have different surface geometries, at least one of these surfaces being aspheric.

Preferably, that one of the two lens assemblies which is designed to compensate for changing spherical aberration is located closer to the medium. One of the two lens assemblies which is designed to perform the majority of light

15 bending may be configured to define two lens portions of different materials and geometries. In this case, the lens portions may be separate lens elements arranged in a spaced-apart relationship along the optical axis either with a gap between them or being attached to each other.

Alternatively, that one of the two lens assemblies which is designed to

20 perform the majority of light bending may be located closer to the medium. In this case, the other one of the two lens assemblies may be a multiple-lens assembly, for example including three spaced-apart different lenses.

The variation of the depth of focus is preferably implemented by displacing at least one of the lenses of the focusing/collecting arrangement with respect to at

25 least one other lens thereof along the optical axis, and more preferably displacing only that one of the lens assemblies which is designed to perform the majority of light bending. Generally, however, the entire focusing/collecting arrangement, as well the light source and detector assembly can be movable with respect to each other and/or with respect to the medium.

The correction of chromatic aberrations of focusing/collection may be carried out during the exciting beams' propagation towards the focusing/collecting arrangement and the excited beam propagation from the focusing/collecting arrangement, by pre-shaping the exciting beams and post-shaping of the collected

5 excited beam, while correction of spherical aberration is carried out by the focusing/collecting arrangement. The pre-shaping consists in providing a desired degree of the beam divergence or convergence when arriving at the focusing/collecting arrangement. Several examples of pre-shaping are possible: The pre-shaping may consist in providing a slight divergence or convergence of each of

10 the exciting beams, thereby providing semi-infinite conjugation of the exciting beams. The pre-shaping may consist in providing a larger degree of divergence or convergence of each of the exciting beams, so as to provide finite conjugation of the exciting light beams. The pre-shaping may consist in collimating one of the first and second exciting light beams and providing a slight divergence/convergence of

15 the other exciting beam when arriving to the focusing/collecting arrangement so as to provide the semi-infinite conjugation of said other beam. The pre-shaping may include collimation of each of said first and second exciting light beams. The post-shaping of the excited light beam consists of providing a desired divergence or convergence of the excited beam when arriving at the detector assembly.

20 The first and second exciting beams may be, respectively, reading and recording light beams, or both be reading or recording light beams.

Thus, the present invention is directed to a lens actuator assembly for an optical head comprising:

25 a lens system comprising a first lens arrangement and a second lens arrangement for focusing a beam of radiation in a focusing direction;

 a first electromagnetic actuator for actuating at least said first lens arrangement in a focusing direction;

 a second electromagnetic actuator for actuating at least said second lens

30 arrangement in a focusing direction;

wherein at least a part of said first electromagnetic actuator is located at the same axial position as at least a part of said second electromagnetic actuator along the direction of the optical axis of the lens actuator assembly.

In some embodiments, a common magnet arrangement provides a 5 suitable magnetic field common to both said actuators, enabling operation of each said actuator when a suitable electric current is provided thereto.

In preferred embodiments, the first actuator comprises a pair of first coils one each mounted to opposed ends of a housing, said housing accommodating said first lens at an aperture thereof aligned in said focusing direction. The first 10 actuator comprises a first magnet arrangement comprising a first plate magnet mounted to a base in opposed relationship to one said first coil and a second plate magnet mounted to said base in opposed relationship to the other said first coil. The housing is elastically mounted to said base such as to enable said housing to move in at least said focusing direction while maintaining alignment between 15 said first coils and said first and second plate magnets. The housing is mounted to said base via a plurality of resilient members connected at one end thereof to said base and at another end thereof to said housing.

The first and second plate magnets each comprise a first pair of bar magnets aligned in series in the focusing direction and arranged such that for 20 each said pair of bar magnets, each bar magnet exposes a different pole with respect to a said first coil that is mounted in opposition thereto. The first coils are substantially rectangular, each said first coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said first pair of bar magnets that is mounted in opposition to said first coil. The second lens 25 arrangement is accommodated in a lens holder at an aperture thereof aligned in said focusing direction, wherein said lens holder is elastically mounted to said housing via a suspension system.

The second actuator comprises a pair of second coils mounted to opposed ends of said lens holder. Each one of the second coils is in substantially opposed 30 relationship with respect to one or another said first pair of bar magnets. The

second coils are substantially rectangular, each said second coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a bar magnet of said pair of bar magnets that is mounted in opposition to said first coil. The suspension system is configured to enable said lens holder to move in

5 at least said focusing direction while maintaining alignment between said second coils and said second magnets arrangement. Further, the suspension system is particularly configured to enable said lens holder to move in at least said focusing direction while substantially maintaining alignment, and thus avoiding decentering or tilt, between said first lens arrangement and said second

10 arrangement along an optical axis of said lens system.

In the first embodiment, the suspension system comprises first and second mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element being elastically deformable along the focusing direction. The first mounting

15 element is mounted to said housing, and wherein said second mounting element is mounted to said lens holder. The first mounting element is connected to said second mounting element via substantially rigid spacing members at the transverse ends of said mounting elements. The first and second mounting elements each comprise a pair of leaf springs joined to a central mounting ring.

20 The second actuator may optionally also comprise said first magnet arrangement, and thus the first magnet arrangement effectively also constitutes the second magnet arrangement, or alternatively the second actuator may comprise a separate second magnet arrangement. The second actuator comprises a pair of second coils mounted to opposed ends of said lens holder. The second

25 magnet arrangement may comprise two opposed second pairs of bar magnets, each bar magnet of each pair being aligned in series in the focusing direction and arranged such that for each said second pair of bar magnets, each bar magnet exposes a different pole with respect to a said second coil that is mounted in opposition thereto. Each said second coil is in substantially opposed relationship

30 with respect to one or another of said second pair of bar magnets. The second

coils may be substantially rectangular, each said second coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a bar magnet of said second pair of bar magnets that is mounted in opposition to said second coil.

5 Optionally, the first magnet arrangement and said second magnet arrangement are disposed substantially orthogonally one to the other with respect to said optical axis of said assembly.

In the second embodiment, the said suspension system comprises a first
10 pair and a second pair of mounting elements spaced one from the other along the focusing direction and each extending transverse from the focusing direction, each mounting element thereof being elastically deformable along the focusing direction. The first pair of mounting elements is mounted to said housing at opposed inner sides thereof, and wherein said second pair of mounting elements
15 is mounted to said lens holder one each at an upper end and lower end thereof. The first pair of mounting elements is connected to said second pair of mounting elements via substantially rigid spacing members at the transverse ends of said mounting elements. Each said mounting element said first and second pair of mounting elements comprises a pair of leaf springs joined to a central mounting
20 ring.

Preferably, the lens actuator further comprising a third electromagnetic actuator for actuating at least said first lens arrangement in a tracking direction substantially orthogonal to said focusing direction. The third actuator comprises at least one pair and preferably two pairs of third coils mounted to said opposed
25 ends of said housing. An auxiliary magnet arrangement provides a suitable magnetic field to said third actuator, enabling operation of said third actuator when a suitable electric current is provided thereto. The auxiliary magnet arrangement comprises, for each said third coil, a second pair of bar magnets mounted to said base in opposed relationship to said third coil. Each second pair
30 of bar magnets is aligned in series in the tracking direction and arranged such

that for each said second pair of bar magnets, each bar magnet exposes a different pole with respect to a said third coil that is mounted in opposition thereto. Each third coil is positioned adjacent to a corresponding said first coil at each said end of said housing along said tracking direction. The third coils are 5 substantially rectangular, each said third coil comprising a pair of coil arms each of which is substantially aligned with a corresponding pole of a said second pair of bar magnets that is mounted in opposition to said third coil.

In a third embodiment of the invention, the focusing coils for the objective lens assembly and the height control coils for the corrector lens 10 assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane both sets of coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of 15 vertically disposed magnets.

In a fourth embodiment of the invention, the focusing coils for the objective lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to 20 the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets.

In a fifth embodiment of the invention, the height control coils for the corrector lens assembly may be similar to those described with respect to the first 25 or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets

The second lens is typically an objective lens and said first lens is an auxiliary lens. The lens system is adapted for enabling a beam of radiation to be focused at any desired depth within a three-dimensional optical data carrier; the depth is typically in the range of about 0 to about 3mm. The lens system is
5 adapted for enabling a beam of radiation to be focused at any desired depth within a range of depths such as to enable said beam to be focused at a data layer of an information carrier, wherein said information carrier may include any one of a range of different types of information carriers each having at least one data layer at a different depth within said range of depths. The different types of
10 information carriers may include at least one of a CD, a DVD and a BluRay disc.

The first lens arrangement is typically positioned about 100 microns to about 400 microns from the surface of an information carrier that it is intended to read/write information with respect to. The first lens arrangement may include a meniscus lens, and the second lens arrangement may include a biconvex lens.

15 The said lens system is typically adapted for enabling a beam of radiation to be focused at any desired depth within a three-dimensional optical data carrier and for enabling collection of signals from said carrier.

Thus, the present invention is also directed to a lens actuator assembly for
20 an optical head comprising:

a first lens assembly comprising a first lens arrangement and a first electromagnetic actuator for actuating at least said first lens arrangement in a focusing direction;

25 a second lens assembly comprising a second lens arrangement and a second electromagnetic actuator for actuating at least said second lens arrangement in a focusing direction;

wherein said first lens assembly is at least partially nested within said second lens assembly, and wherein said first lens arrangement and said second lens arrangement are adapted for focusing a beam of radiation in a focusing
30 direction.

In particular, at least a part of the first actuator – typically a coil arrangement thereof – is nested within at least a part of the second actuator – typically a coil arrangement thereof.

5 BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is an exploded isometric view of the first embodiment of the 10 present invention.

Fig. 2 is a collapsed isometric view of the embodiment of Fig. 1.

Fig. 3 is an exploded isometric view of the main lens assembly of the embodiment of Fig. 1.

Fig. 4 is a collapsed isometric view of the main lens assembly of Fig. 3.

15 Fig. 5 is an isometric view of the magnet arrangement of the embodiment of Fig. 1.

Fig. 6 is an exploded isometric view of the second embodiment of the present invention.

20 Fig. 7 is an exploded isometric view of the main lens assembly of the embodiment of Fig. 6.

Fig. 8 is a collapsed isometric cross-sectional view along the focus/tracking plane of the main lens assembly of Fig. 7.

Fig. 9 is an exploded isometric view of the third embodiment of the present invention.

25 Fig. 10 is an exploded isometric view of the fourth embodiment of the present invention.

Fig. 11 is an exploded isometric view of the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Herein, the term "focusing direction" refers to a direction substantially perpendicular to the plane comprising the information that it is required to read from or write to in an optically scannable information carrier, such as a DVD or CD, and particularly a three-dimensional storage medium or multi-layer carrier, typically in the form of a disc. The focusing direction coincides with the optical axis of the optical head. The term "tracking direction" refers to a substantially radial direction with respect to the carrier, and the term "tangential direction" refers to a direction substantially tangential to the carrier.

The construction of the optical information carrier does not form part of the present invention, except to note that may be one of ROM (Read Only Memory), WORM (Write Once Read Many), and recordable (rewritable) memory types.

More specifically, the present invention is preferably used with a data storage medium in the form of a monolithic translucent substrate. The monolithic nature of the storage material entails a uniformity of the optical parameters of the carrier – typically shaped as a disk - resulting in a homogeneous index of refraction and absorption coefficient throughout the disk. This allows for designing the focusing device with an aberration corrector of a known range of motion and overall behavior. The disk may for example be designed as described in WO 01/73779 and WO 03/070689, both assigned to the assignee of the present application. According to this technique, the substrate medium (active medium, e.g., including diarylalkene derivatives, triene derivatives, polyene derivatives or a mixture thereof) is of the type capable of changing from a first isometric form to a second isometric form in response to a light beam having energy substantially equal to first threshold energy. The concentration ratio between the first and second isometric forms in any given volume portion represents a data unit. The active medium may be embedded in a supporting matrix, which may be a polymer, and the active medium is chemically

bound thereto. Alternatively the supporting matrix may be a wax or a micelle and the active medium is homogeneously distributed therein. The information is stored as a series of data units. Data reading is based on reading data units from the isomeric states of the active medium in different portions of the active medium,

5 where the two isomeric forms have a substantially different absorption coefficient for absorbing energy of second threshold energy. Reading may also be carried out by measuring the scattering pattern of the two isomeric forms. The disk may be provided with a specific coating, for example for the purposes of protecting it against UV radiation. The disk may for example be protected within a cartridge.

10 In the monolithic active medium, a data layer is considered as one data set inscribed at a specific depth (within a specified tolerance). Layers with very tight depth tolerance can be considered as having fixed depth. Layers with loose depth tolerances will be termed as layers with variable depth. Data is recorded (written/erased) in a specified layer by changing the state of the substrate within

15 a localized volume element, defined by the focus of the read/write/erase optical beams. The present invention provides for dynamic focusing of light beams of different wavelengths in a large number of layers with fixed depths, and in a large number of layers of variable depth.

20 While reading/recording data in a three-dimensional storage medium (e.g., a monolithic translucent material), incident light beams of different wavelengths after passing through a lens arrangement traverse two distinct materials (e.g., air followed by a clear plastic) and is focused within the second material (storage medium). Correction of chromatic and spherical aberrations may be provided by

25 tailoring the focusing/collecting arrangement to enable focusing of two exciting light beams of different wavelengths onto desirably distanced from each other sites in the medium and detecting excited light coming from the medium while correcting for chromatic and spherical aberrations of focusing/collection. This is implemented by appropriately designing the focusing/collecting arrangement (i.e., a

30 number of lenses, their relative accommodation and geometry) to adjust a degree of

divergence/convergence of the exciting light beams' when arriving to the focusing/collecting arrangement, as well as the collection of the excited light, and the light propagation in between the focusing/collecting arrangement and the medium. It should be noted that with regard to excited light, the focusing/collection

5 assembly receives a portion of this light impinging onto the focusing/collecting arrangement and forms an excited light beam to propagate towards a detector assembly. Thus, the term "excited light beam" or "excited beam" used herein signifies either one of excited radiation or shaped excited beam, depending on the excited light propagation location, namely, respectively, between the
10 focusing/collecting arrangement and the medium, and between the focusing/collecting arrangement and a detector assembly.

The focusing and collecting include passing the exciting light beams and the excited light through the same focusing/collecting arrangement. The geometry of the focusing/collecting arrangement and its accommodation relative to the medium
15 and to light source and detector assemblies are optimized to be capable of focusing each of the exciting light beams to said desirably distanced from each other sites in the medium and detecting the beam of the collected excited light coming from the excited site in the medium.

20 Referring to Figs. 1 and 2, a first embodiment of the lens actuator assembly for an optical head, generally designated with the numeral 10, is illustrated in isometric view, exploded and collapsed, respectively. In operation, the lens actuator assembly 10 is controlled by actuators in both the focus and tracking drive directions, as will be described in greater detail hereinbelow.
25 Further control of the radial direction enables the lens actuator assembly 10 to move from one track to another track within the carrier, and many arrangements for so doing are known in the art and will not be described further herein.

In the first embodiment, the lens actuator assembly 10 comprises a
30 corrector lens assembly 15, comprising a lens holder 20, which is generally box

like and preferably in the form of an inverted U-section, having an upper opening 21 in which a correcting or auxiliary lens 30 is mounted. The correcting lens 30 is aligned with the optical axis OA of the lens actuator assembly 10. The corrector lens assembly 15 further comprises a pair of coil boards 22, 24, 5 substantially coplanar with the tracking/focus drive directions, and mounted onto the open ends of the lens holder 20. The coil boards 22, 24 each comprise a centrally fixed rectangular height control coil 32. A pair of rectangular tracking coils 33, 35 are provided, one each on either side of the height control coil 32 to provide tracking actuation, for each coil board 22, 24.

10

The corrector lens assembly 15 is received between a pair of composite plate magnets 52, 54, which are mutually parallel one to the other and which are also parallel to the coil boards 22, 24. The plate magnets 52, 54 are also spaced such as to provide a suitable air gap between each plate magnet 52, 54 and the 15 corresponding coil board 22, 24, respectively. Accordingly, the plate magnets 52, 54 are mounted onto a U-shaped magnet mount 72, which is itself fixed onto a base 70. The corrector lens assembly 15 is also supported by and mounted onto the base 70, via a number, typically eight, of resilient support elements such as wires 75, which are connected to the lens holder 20 at one end thereof, and 20 rigidly mounted to a support bracket 76 at the other end of. The support bracket 76 is in turn mounted onto the base 70. The wires 75 are arranged on two spaced planes, and are arranged substantially parallel to the tangential direction when unstressed, thus allowing movement of the optical head 20 in both the focusing and tracking directions with respect to the base 70.

25 Alternatively, the wires 75 may be supported at both ends thereof, for example by employing a second support bracket in opposed relationship to the aforementioned support bracket 75, to minimize tilt of the optical head 20 and the lenses and actuators therein, when said actuators are operated.

30 Alternatively, the wires 75 and support bracket 76 may be replaced with any other suitable elastic suspension arrangement capable of allowing the

necessary movement in the tracking and focusing directions. In other embodiments, the wires may be at some desired angle to the tangential direction rather than aligned therewith when unstressed.

The base 70 and the magnet mount 72 each comprise apertures 71, 73, 5 respectively, which are aligned with the optical axis OA of the corrector lens 30 (and of objective lens 130 – see Figure 3) and also with a suitable radiation source of an optical module (not shown), for example a laser, which supplies a radiation beam to the optical information carrier via the lens actuator assembly 10 during operation thereof.

10 Referring to Fig. 5, the magnet arrangement for plate magnets 52, 54 is illustrated. Plate magnet 54 comprises a pair of central bar -shaped magnets mounted one over the other and arranged such that the upper magnet 81 has a North Pole facing a coil arm of the height control coil 32 of coil board 24, and the lower magnet 82 has a South Pole facing another coil arm of the height 15 control coil 32 of coil board 24. The plate magnet 54 also comprises a pair of magnets 83, 84 adjacent to the central magnets 81, 82 along the tracking direction. The magnets 83, 84 are mounted one next to the other and arranged such that magnets 83 84 have a North Pole and a South Pole, respectively, facing spaced coil arms of the tracking coils 33 of coil board 24. The plate magnet 54 20 also comprises another pair of magnets 85, 86 adjacent to the central magnets 81, 82 and on the other side thereof along the tracking direction. The magnets 85, 86 are mounted one next to the other and arranged such that magnets 85, 86 have a North Pole and a South Pole, respectively, facing the coil arms of tracking coils 35 of coil board 24. Alternatively, the magnets may be arranged with reverse 25 polarities to those described above. A similar arrangement is provided for the second plate magnet 52, in which the polarities of the individual magnets therein may similar to, or alternatively reversed with respect to those described for first plate magnet 54.

Thus, an electromagnetic actuator is provided for the auxiliary lens 30, 30 comprising the height control coils 32 and the magnets 81, 82, for actuating the

lens 30 in the focusing direction. Another electromagnetic actuator is provided for the auxiliary lens 30, comprising the tracking coils 33, 35 and the magnet pairs 83, 84 and 85, 86 for actuating the lens 30 in the tracking direction

5 In operation, the current in the height control coils 32 is proportional to the height servo error signal corresponding to the focus drive direction. This signal relates to the displacement between the corrector lens 30 and the surface of the data carrier, typically in the form of a disc. The electro-magnetic force which is generated by these coils is proportional to the product of the coil current I and
10 the external magnetic flux density H (i.e., that is caused by the magnets 81, 82 of the plate magnets 52, 54), and the direction of the electro-magnetic force F is along the coil surface and parallel to the optical axis **OA**. Thus the height control coils 32 move up and down along the focusing direction according to the polarity of the coil current, until the height servo error signal is reduced to zero. With
15 respect to the tracking drive coils 33, 35, a similar situation exists to that described for the height control coils 32, except that the each of the tracking drive coils 33, 35 interact with the corresponding magnet pairs 83, 84 and 85, 86, respectively, and move to the right or the left along the tracking direction according to the servo signals supplied by the appropriate tracking optical unit,
20 for example according to the method as described in US 2003/0174594 (assigned to the present assignee), the contents of which are incorporated herein in their entirety.

25 The lens actuator assembly 10 according to the present invention is adapted for scanning any one of a plurality of different depths within the carrier, and thus comprises a main or objective lens assembly 100 that performs the majority of the light bending required for the focusing of radiation at a particular depth in the information carrier. The corrector lens 30, when used with the main lens assembly 100, may comprise, for example a meniscus lens, and in any case
30 mainly compensates for the changing spherical aberration introduced by the

changing of the thickness into which the radiation is being focused, but also provides some focusing of the radiation. The combination and specific optical properties of lenses 130, 30 enable a beam of radiation to be focused at any one of a plurality of depths within the carrier.

- 5 Referring in particular to Figs. 3 and 4, in the first embodiment, the main lens assembly 100 is nested within the corrector lens assembly 15, and comprises an objective or main lens 130 mounted onto a main lens holder 140. The main lens holder 140 comprises a cylindrical element 145 which is adapted for accommodating the main lens 130, and two pairs of radial struts 142, 144, one pair each projecting from either side thereof. The main lens assembly 100 further comprises a pair of coil boards 122, 124, substantially coplanar with the tracking/focus drive directions, and mounted onto the free ends of strut pairs 142, 144 of the main lens holder 140. The coil boards 122, 124 each comprise a centrally fixed rectangular focusing coil 132. The main lens assembly 100 is
- 10 adapted for movement along the focusing direction within the corrector lens assembly 15, and independently thereof. Accordingly, a suspension system is provided enabling the main lens 130 to move along the optical axis OA with respect to the corrector lens 30. The suspension system comprises spaced mounting elements. One mounting element includes a pair of upper plate or leaf
- 15 springs 182, 184, which are in their unstressed state aligned substantially parallel to the focusing direction, and each is mounted at an inner end thereof to the underside 27 of the lens holder 20. Advantageously, the upper leaf springs are integrally joined one to the other via central ring member 183, which is press-fitted or otherwise fixed onto a circular mount 28 co-axial with the opening 21.
- 20 The other mounting element of suspension system comprises a pair of lower leaf springs 186, 188, which are in their unstressed state aligned substantially parallel to the focusing direction, and also to the upper leaf springs 182, 184. Each lower leaf spring 186, 188 is mounted at an inner end thereof to the underside 147 of the main lens holder 140. Advantageously, the lower leaf springs are integrally
- 25 joined one to the other via central ring member 187, which is press-fitted or
- 30

otherwise fixed onto a circular mount 148 co-axial with the cylindrical element 145. Substantially rigid spacer elements 152, 154 connect the free ends of pairs of leaf springs 182, 186 and 184, 188, respectively. The spacer elements 152, 154 provide a spacing between the upper leaf springs 182, 184 and the lower leaf 5 springs 186, 188, greater than the height of the cylindrical element 145 along the focusing direction.

The spring arrangement for the suspension system allows movement of the main lens 130 along the optical axis OA without introducing any substantial decentering or tilt of the objective lens 130 with respect to the corrector lens 30.

10

In this embodiment, the plate magnets 52, 54, and in particular the central magnets 81, 82 of each said plate magnet, are considered to be "common magnets" and are thus also used for providing the magnetic flux used in actuation of the objective focus drive coils, i.e. depth focusing coils 132. Thus, for plate 15 magnet 54 the upper magnet 81 has a North Pole facing a coil arm of the focusing coil 132 of coil board 124, and the lower magnet 82 has a South Pole facing another coil arm of the focusing coil 132 of coil board 124. A similar arrangement exists between plate magnet 52 and the focusing coil 132 of coil board 122.

20

In operation, the current in the objective focus drive coils 132 is proportional to the depth servo signal corresponding to the desired depth in which it is desired to read/write information within the three-dimensional information medium, along the focus drive direction. This signal is modified by 25 bulk movement of the information layer due to "wobble" and other instabilities in the attitude of the carrier. The electro-magnetic force which is generated by these coils 132 is proportional to the product of the coil current I' in coils 132 and the external magnetic flux density H' (i.e., that is caused by the central magnets 81, 82 of the plate magnets 52, 54, and the direction of the electro-magnetic force F' 30 is parallel to the coil surface and in a direction substantially parallel to the optical

axis **OA**. Thus the depth focusing coils **132** move up and down along the focusing direction according to the polarity of the coil current, until the depth servo error signal is reduced to zero.

Thus, another electromagnetic actuator is provided for the objective lens **130**, comprising the depth focusing coils **132** and the magnets **81, 82**, for actuating the lens **130** in the focusing direction. In this embodiment, this actuator is nested within the previously-mentioned electromagnetic actuator for the auxiliary lens **30**, comprising the height control coils **32** and the magnets **81, 82**, for actuating the lens **30** in the focusing direction. The coils **32** are nested within coils **32** with respect to the optical axis, and thus at least partially overlap with respect to this axis, and both sets of coils use the same magnets **81, 82** (of each plate magnet **52, 54**).

In operation, the lens assemblies **15, 100** are actuated independently one from the other. The objective lens assembly **100** is actuated to maintain the beam of radiation focused at a particular data layer within the carrier, and a depth servo error signal is provided by a suitable sensing system for controlling this actuation, for example as disclosed in the aforementioned US 2003/0174594. The correction lens assembly **15** is actuated in the tracking direction for maintaining the beam within a track, and a tracking error signal is provided by a suitable sensing system for controlling this actuation, for example as disclosed in the aforementioned US 2003/0174594. The correction lens assembly **15** is also actuated in the focusing direction for maintaining a constant distance or displacement between the corrector lens **30** and the surface of the data carrier or disc such as to prevent spherical aberration, and a displacement error signal is provided by a suitable sensing system for controlling this actuation.

Thus the lens assemblies **100** and **15** are arranged in an overlapping relationship along an optical axis **OA** defined by these lens assemblies, such that the corrector lens **30** is accommodated downstream of the main lens **130**, i.e., closer to the information carrier. The lenses **130** and **30** are appropriately

designed to correct for spherical aberrations, while typically scanning various depths in the carrier by two beams of different wavelengths. At least one of the lenses' surfaces is typically aspheric, with no need for complementary shapes of the lens' surfaces.

5 In the first embodiment, the corrector lens 30 is kept at a certain substantially fixed distance from the information carrier, typically in the range of about 100 – about 400 microns, and the objective lens 130 is movable. This provides for the simplicity and applicability of the design, as far as mechanics and feedback mechanisms are concerned. Generally, however, at least one of the
10 other elements may be movable as well, namely, as far as degrees of freedom are concerned, one or more optical elements of the system can be moved. In other embodiments, the corrector lens, and possibly both lenses are movable along the optical axis.

15 The radiation source of the optical module (not shown) that supplies a radiation beam to the optical information carrier via the lens actuator assembly
10 during operation thereof does not necessarily need to be moved in the focusing direction, particularly if collimated or near-collimated radiation is used. Optionally, though, a suitable actuator may also be provided for moving the
20 radiation source in the focusing direction.

 The lens actuator assembly of the present invention is particularly useful for reading/writing with respect to a three-dimensional optical disc, typically but not limited to a depth ranging from about 0mm to about 3mm. Furthermore, the lens assembly may also be used in many other applications, and finds particular
25 use in a multifunction drive that can read/write to different types of discs, for example with respect to a CD disc of 1.2mm thickness and/or with respect to a DVD disc with 0.6mm thickness, and/or with respect to BluRay discs with 0.1mm thickness. Thus, the lens actuator assembly of the present invention may also be retrofitted with respect to multifunction drives, or be included in the

design of new multifunction drives, which can be used with any number of different types of discs, each having data at different depths from the other discs.

A second embodiment of the invention, illustrated in Figs. 6, 7 and 8, 5 comprises all the elements of the first embodiment with a few differences, as described herein *mutatis mutandis*.

Thus, the second embodiment of the lens actuator assembly for an optical head, generally designated with the numeral 10', is similar in function and operation to that of the first embodiment, and comprises a corrector lens 10 assembly 15', comprising a lens holder 20', which is generally box like and for this embodiment is closed at the lower end, having an upper opening 21' in which a correcting lens 30' is mounted, and a lower opening 23' aligned therewith along the optical axis OA of the lens actuator assembly 10'. The corrector lens assembly 15' further comprises a pair of coil boards 22', 24' (each 15 comprising height coils 32', and tracking coils 33', 35'), substantially coplanar with the tracking/focus drive directions, and mounted onto the opposed open ends of the lens holder 20' in a similar manner to the elements described for the first embodiment, *mutatis mutandis*. The corrector lens assembly 15' is received between a pair of composite plate magnets 52, 54, which are mounted onto a U- 20 shaped magnet mount 72 and base 70, as described for the first embodiment, *mutatis mutandis*. The corrector lens assembly 15' is also supported by and mounted onto the base 70, via a number, typically eight, of resilient support elements such as wires 75.

The lens actuator assembly 10' according to the second embodiment also 25 comprises a main lens assembly 100', which comprises an objective or main lens 130' mounted onto a main lens holder 140'. As with the first embodiment, the main lens holder 140' also comprises a cylindrical element 145' which is adapted for accommodating the main lens 130', and two pairs of radial struts 142', 144', one pair each projecting from either side thereof, and a pair of coil boards 122', 30 124', each having a depth focusing coil 132'.

The main lens assembly 100' in the second embodiment differs from that of the first embodiment as follows. The suspension system comprises four spaced mounting elements. Referring particularly to Figs. 7 and 8, a first mounting element includes a pair of upper plate or leaf springs 182', 184', which are in 5 their unstressed state aligned substantially parallel to the focusing direction, and each is mounted at an inner end thereof to the underside 27' of the lens holder 20'. Advantageously, the upper leaf springs are integrally joined one to the other via central ring member 183, which is press-fitted or otherwise fixed onto a circular mount 28 co-axial with the opening 21. A second mounting element, 10 similar to the first mounting element, also comprises a pair of leaf springs 282', 284' integrally joined one to the other via central ring member 283', which is press-fitted or otherwise fixed onto a circular mount 29' co-axial with the opening 23.

A third mounting element of suspension system comprises another pair of 15 leaf springs 186', 188', which are in their unstressed state aligned substantially parallel to the focusing direction, and also spaced with respect to the upper leaf springs 182', 184'. Each leaf spring 186', 188' is mounted at an inner end thereof to the upper side 147' of the main lens holder 140'. Advantageously, the leaf springs 186', 188' are integrally joined one to the other via central ring member 20 187', which is press-fitted or otherwise fixed onto a circular mount 148 co-axial with the cylindrical element 145' at an upper end of main lens holder 140'. A fourth mounting element, similar to the third mounting element, also comprises a pair of leaf springs 286', 288' integrally joined one to the other via central ring member 287', which is press-fitted or otherwise fixed onto a circular mount 248' 25 co-axial with the cylindrical element 145' at a lower end of main lens holder 140'.

Substantially rigid spacer elements 152', 154' connect the free ends of groups of leaf springs 182', 186', 286', 282' and 184', 188', 288', 284' respectively.

Thus, as with the first embodiment, the spring arrangement for the 30 suspension system allows movement of the main lens 130' along the optical axis

OA without introducing any substantial decentering or tilt of the objective lens 130' with respect to the corrector lens 30'.

Operation of the second embodiment is substantially similar to that described for the first embodiment, *mutatis mutandis*.

5 In other embodiments of the invention, the coil boards 22, 24, may only comprise a single tracking coil each, and/or more than one focusing coil, and the plate magnets 52, 54 are configured accordingly.

In other variations of the embodiments described herein, the corrector lens 10 assembly 15 or 15' may be designed such that the corresponding tracking coils are formed as a single coil rather than a pair of spaced coils in the tracking direction, and this single coil may be centrally located on the corresponding coil board, similarly to that shown for the height control coil 32 in Fig. 1. At the same time, the height control coil of such embodiments may be split into two or more 15 coils and for example located in the position shown for the tracking coils 32, 33 in Fig. 1. In other words, the magnet arrangement of the plate magnets is modified, such that the magnets 81, 82 are aligned parallel to the tracking direction rather than the focusing direction shown in Fig. 5, and the magnets 83, 84 and 85, 86 are aligned in the focusing direction rather than the tracking 20 directions shown in Fig. 5. In such an embodiment, the focusing coils 132 of the objective lens assembly 100 may be corresponding split, and in any case aligned in the tracking direction with the newly positioned magnets 81, 82.

In a third embodiment of the present invention, and referring to Fig. 9, the 25 lens actuator assembly 310 is similar to the first embodiment described above *mutatis mutandis*, but comprises a different arrangement thereto for the axial actuator arrangements for the objective lens assembly 301 and the corrector lens assembly 315, as well as some other corresponding differences in structure, as will be further described hereinbelow.

Thus, as with the first embodiment, the lens actuator assembly 310 comprises a corrector lens assembly 315, comprising a lens holder 320, which is, however, generally table-like and preferably in the form of an upper panel having an upper opening 321 in which a correcting lens 330 is mounted aligned with the 5 optical axis OA of the lens actuator assembly 310, and four legs 302 at the corners to form two orthogonal pairs of openings 303, 304 in the tangential and tracking directions, respectively. The corrector lens assembly 315 further comprises a pair of coil boards 322, 324, substantially coplanar with the tracking/focus drive directions, and mounted onto two opposed open ends 303 of 10 the lens holder 320. The coil boards 322, 324 each comprise a centrally fixed rectangular tracking coil 335 to provide tracking actuation, for each coil board 322, 324. Another pair of coil boards 328 are provided, substantially coplanar with the focus/tangential plane, and mounted onto two opposed open ends 302 of the lens holder, i.e., orthogonally disposed with respect to coil boards 322, 324. 15 A pair of rectangular height control coils 332 are provided, one each on said boards 328. Thus, in this embodiment, the height control coils 332 are now aligned in the focus/tangential plane rather than the focus/tracking plane.

In other embodiments, the height control coils may be oriented at any angular disposition with respect to the optical axis, and may be non-planar is 20 desired, so long as actuation thereof is possible in the focusing direction.

The objective lens assembly 301 is substantially similar to that described for the first embodiment, *mutatis mutandis*, but is now set at 90° with respect thereto. The objective lens assembly 301 according to the third embodiment thus comprises: an objective or main lens 306 mounted onto a main lens holder 340 25 having a cylindrical element and two pairs of radial struts; a pair of coil boards 312, 314, each having a centrally fixed rectangular focusing coil 313, and mounted onto the free ends of strut pairs of the holder 340; a suspension system comprising spaced mounting elements, including leaf springs 382, 384, joined via central ring member 383, a pair of lower leaf springs 386, 388, via central 30 ring member 387, and substantially rigid spacer elements 389. As with the first

embodiment, the spring arrangement for the suspension system allows movement of the main lens 306 along the optical axis OA without introducing any substantial decentering or tilt of the objective lens 306 with respect to the corrector lens 330. Thus, in this embodiment, the focusing coils 313 are now 5 aligned in the focus/tangential plane rather than the focus/tracking plane.

In other embodiments, the focusing coils may be oriented at any angular disposition with respect to the optical axis, and may be non-planar if desired, so long as actuation thereof is possible in the focusing direction.

Alternatively, the objective lens assembly 301 is substantially similar to 10 that described for the second embodiment, with corresponding differences as described above, *mutatis mutandis*,

The corrector lens assembly 315, comprising the objective lens assembly 301 inside thereof, is received between two orthogonally arranged pairs of composite plate magnets 352, 354. One pair of plate magnets 352 are mutually 15 parallel and are also parallel to the coil boards 322, 324. The other pair of plate magnets 354 are also mutually parallel one with the other, but are also parallel to the coil boards 328 and coil boards 312, 314. Each of the plate magnets 352, 354 are also spaced such as to provide a suitable air gap between the plate magnet pair 352, and the corresponding coil board 322, 324, and between the plate 20 magnet pair 354, and the corresponding coil board 328. Thus, one plate magnet pair 352 may be mounted onto a U-shaped magnet mount 372, which is itself fixed onto a base 370. The other pair of plate magnets 354 may be mounted to another U-shaped mount, or, as illustrated in Fig. 9, to walls 357 joined to base 370.

25 The magnet pair 352 may comprise an arrangement of magnets (not shown) similar to bar magnets 83, 84 or 85, 86 described for the first embodiment, *mutatis mutandis*, and interacts with coils 335 in a similar manner to that described for each pair of coils 33, 35 of the first embodiment, *mutatis mutandis*. The magnet pair 354 may comprise an arrangement of magnets (not 30 shown) similar to bar magnets 81, 82 described for the first embodiment, *mutatis*

mutandis, and interacts with coils 332 and coils 313 in a similar manner to that described for coils 32 and coils 38 of the first embodiment, *mutatis mutandis*.

The corrector lens assembly 315 is also supported by and mounted onto the base 370, via a suitable number of resilient support elements 375 similar to that described for the first embodiment *mutatis mutandis*, thus allowing movement of the lens holder 320, together with lenses 330 and 306 in both the focusing and tracking directions with respect to the base 370. The base 370 and the magnet mount 372 each comprise apertures 371, 373, respectively, which are aligned with the optical axis OA of the corrector lens 330 and of objective lens 306 and also with a suitable radiation source of an optical module (not shown), for example a laser, which supplies a radiation beam to the optical information carrier via the lens actuator assembly 310 during operation thereof.

Thus, the focusing coils for the objective lens assembly and the height control coils for the corrector lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane both sets of coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair 81, 82. This arrangement also provides a mechanical force independently to each one of the objective lens assembly 301 and the corrector lens assembly 315 in the focusing direction, and again a common magnet arrangement 354 is used for actuation of both actuators in the focusing direction.

In a fourth embodiment of the present invention, and referring to Fig. 10, the lens actuator assembly 410 is similar to the first embodiment described above *mutatis mutandis*, but comprises a different arrangement thereto for the actuator arrangements for the objective lens assembly 401, as well as some other corresponding differences in structure, as will be further described hereinbelow.

Thus, as with the first embodiment, the lens actuator assembly 410 comprises a corrector lens assembly 415, comprising a lens holder 420, which is,

however, generally wider in the tangential direction to accommodate a different configuration for the objective lens assembly 401, having opening 421 in which a correcting lens 430 is mounted aligned with the optical axis OA of the lens actuator assembly 410. The corrector lens assembly 415 further comprises a pair 5 of coil boards 422, 424, substantially coplanar with the tracking/focus drive directions, and mounted onto two opposed open ends of the lens holder 420. Each of the coil boards 422, 424 comprises height control coils 432 and tracking coils 435 to provide height and tracking actuation, similar in structure and operation to the coil boards 22, 24 described above for the first embodiment, 10 mutatis mutandis. Thus, in this embodiment, as with the first embodiment, the height control coils 432 are aligned in the focus/tracking plane.

The objective lens assembly 401 is substantially similar to that described for the third embodiment, *mutatis mutandis*, that is, set at 90° with respect to that of the first embodiment. Thus, the objective lens assembly 401 according to the 15 third embodiment thus comprises: an objective or main lens 406 mounted onto a main lens holder 440 having a cylindrical element and two pairs of radial struts; a pair of coil boards 412, 414, each having a centrally fixed rectangular focusing coil 413, and mounted onto the free ends of strut pairs of the holder 440; a suspension system comprising spaced mounting elements, including leaf springs 20 482, 484, joined via central ring member 483, a pair of lower leaf springs 486, 488, via central ring member 487, and substantially rigid spacer elements 489. As with the third embodiment, the spring arrangement for the suspension system allows movement of the main lens 406 along the optical axis OA without introducing any substantial decentering or tilt of the objective lens 406 with 25 respect to the corrector lens 430. Thus, in this embodiment, the focusing coils 413 are now aligned in the focus/tangential plane rather than the focus/tracking plane.

Alternatively, the objective lens assembly 401 is substantially similar to that described for the second embodiment, with corresponding differences as 30 described above, *mutatis mutandis*,

The corrector lens assembly 415, comprising the objective lens assembly 401 inside thereof, is received between two orthogonally arranged pairs of composite plate magnets 452, 454. One pair of plate magnets 452 are mutually parallel and are also parallel to the coil boards 422, 424. The other pair of plate 5 magnets 454 are also mutually parallel one with the other, but are also parallel to the coil boards 412, 414. Each of the plate magnets 452, 454 are also spaced such as to provide a suitable air gap between the plate magnet pair 452, and the corresponding coil board 422, 424, and between the plate magnet pair 454, and the corresponding coil board 412, 414. Thus, one plate magnet pair 452 may be 10 mounted onto a U-shaped magnet mount 472, which is itself fixed onto a base 470. The other pair of plate magnets 454 may be mounted to another U-shaped mount, or, as illustrated in Fig. 10, to walls 457 joined to base 470.

The magnet pair 352 may comprise an arrangement of magnets (not shown) similar to bar magnets 81, 82 and 83, 84, 85, 86 described for the first 15 embodiment, *mutatis mutandis*, and interacts with coils 432 in a similar manner to that described for coils 32 of the first embodiment, *mutatis mutandis*, and further interacts with coils 435 in a similar manner to that described for coils 33, 35 of the first embodiment, *mutatis mutandis*.

The magnet pair 454 may comprise an arrangement of magnets (not 20 shown) similar to bar magnets 81, 82 described for the first embodiment, *mutatis mutandis*, and interacts with coils 413 in a similar manner to that described for coils 132 of the first embodiment, *mutatis mutandis*.

The corrector lens assembly 415 is also supported by and mounted onto the base 470, via a suitable number of resilient support elements 475 similar to 25 that described for the first embodiment *mutatis mutandis*, thus allowing movement of the lens holder 420, together with lenses 430 and 406 in both the focusing and tracking directions with respect to the base 470. The base 470 and the magnet mount 472 each comprise apertures 471, 473, respectively, which are aligned with the optical axis OA of the corrector lens 430 and of objective lens 30 306 and also with a suitable radiation source of an optical module (not shown),

for example a laser, which supplies a radiation beam to the optical information carrier via the lens actuator assembly 410 during operation thereof.

Thus, this arrangement also provides a mechanical force independently to each one of the objective lens assembly 401 and the corrector lens assembly 315 5 in the focusing direction.

Thus, in this embodiment, the focusing coils for the objective lens assembly may be similar to those described with respect to the first or second embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to 10 the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair 81, 82. This arrangement also provides a mechanical force to the objective lens assembly in the focusing direction.

15

In a fifth embodiment of the present invention, and referring to Fig. 11 the lens actuator assembly 510 is similar to the third embodiment described above *mutatis mutandis*, but comprises a different arrangement thereto for the actuator arrangements for the corrector lens assembly 515, as well as some other 20 corresponding differences in structure, as will be further described hereinbelow.

Thus, as with the third embodiment, the lens actuator assembly 510 comprises a corrector lens assembly 515, comprising a lens holder 520, which is also generally table-like and preferably in the form of an upper panel having an upper opening 521 in which a correcting lens 530 is mounted aligned with the 25 optical axis OA of the lens actuator assembly 510, and four legs 502 at the corners to form two orthogonal pairs of openings 503, 504 in the tangential and tracking directions, respectively. The corrector lens assembly 515 further comprises a pair of coil boards 522, 524, substantially coplanar with the tracking/focus drive directions, and mounted onto two opposed open ends 503 of 30 the lens holder 520. However, In this embodiment, the coil boards 522, 524 each

comprise a pair of spaced rectangular tracking coils 535 to provide tracking actuation, for each coil board 522, 524. Another pair of coil boards 528 are provided, substantially coplanar with the focus/tangential plane, and mounted onto two opposed open ends 502 of the lens holder, i.e., orthogonally disposed
5 with respect to coil boards 522, 524. A pair of rectangular height control coils 532 are provided, one each on said boards 528. Thus, in this embodiment, the height control coils 532 are now aligned in the focus/tangential plane rather than the focus/tracking plane.

The objective lens assembly 501 is substantially similar to that described
10 for the first embodiment, *mutatis mutandis*, and thus comprises: an objective or main lens 506 mounted onto a main lens holder 540 having a cylindrical element and two pairs of radial struts; a pair of coil boards 512, 514, each having a centrally fixed rectangular focusing coil 513, and mounted onto the free ends of strut pairs of the holder 540; a suspension system comprising spaced mounting
15 elements, including leaf springs 582, 584, joined via central ring member 583, a pair of lower leaf springs 586, 588, via central ring member 587, and substantially rigid spacer elements 589. As with the first embodiment, the spring arrangement for the suspension system allows movement of the main lens 506 along the optical axis OA without introducing any substantial decentring or tilt
20 of the objective lens 506 with respect to the corrector lens 530. Thus, in this embodiment, the focusing coils 513 are aligned in the focus/tracking plane.

Alternatively, the objective lens assembly 501 is substantially similar to that described for the second embodiment, *mutatis mutandis*,

The corrector lens assembly 515, comprising the objective lens assembly
25 501 inside thereof, is received between two orthogonally arranged pairs of composite plate magnets 552, 554. One pair of plate magnets 552 are mutually parallel and are also parallel to the coil boards 522, 524, and to coil boards 512, 514. The other pair of plate magnets 554 are also mutually parallel one with the other, but are also parallel to the coil boards 528. Each of the plate magnets 552,
30 554 are also spaced such as to provide a suitable air gap between the plate

magnet pair 552, and the corresponding coil board 522, 524, and between the plate magnet pair 554, and the corresponding coil board 528. Thus, one plate magnet pair 552 may be mounted onto a U-shaped magnet mount 572, which is itself fixed onto a base 570. The other pair of plate magnets 554 may be mounted 5 to another U-shaped mount, or, as illustrated in Fig. 11, to walls 557 joined to base 370.

The magnet pair 552 may comprise an arrangement of magnets (not shown) similar to bar magnets 81, 82 and 83, 84, 85, 86 described for the first embodiment, *mutatis mutandis*, and interacts with coils 513 in a similar manner 10 to that described for coils 132 of the first embodiment, *mutatis mutandis*, and further interacts with coils 535 in a similar manner to that described for coils 33, 35 of the first embodiment, *mutatis mutandis*.

The magnet pair 554 may comprise an arrangement of magnets (not shown) similar to bar magnets 81, 82 described for the first embodiment, *mutatis 15 mutandis*, and interacts with coils 532 in a similar manner to that described for coils 132 of the first embodiment, *mutatis mutandis*.

The corrector lens assembly 515 is also supported by and mounted onto the base 570, via a suitable number of resilient support elements 575 similar to that described for the first embodiment *mutatis mutandis*, thus allowing 20 movement of the lens holder 520, together with lenses 530 and 506 in both the focusing and tracking directions with respect to the base 570. The base 570 and the magnet mount 572 each comprise apertures 571, 573, respectively, which are aligned with the optical axis OA of the corrector lens 530 and of objective lens 506 and also with a suitable radiation source of an optical module (not shown), 25 for example a laser, which supplies a radiation beam to the optical information carrier via the lens actuator assembly 510 during operation thereof.

Thus, this arrangement also provides a mechanical force independently to each one of the objective lens assembly 501 and the corrector lens assembly 515 in the focusing direction.

Thus, in this embodiment, the height control coils for the corrector lens assembly may be similar to those described with respect to the first or second 5 embodiment, but rather than being aligned along planes parallel to the focus/tracking plane the coils are instead arranged to be in alignment parallel to the focus/tangential plane. Accordingly, a second pair of plate magnets also aligned with this plane is provided, each plate magnet comprising a pair of vertically disposed magnets in a similar manner to magnet pair 81, 82. This 10 arrangement also provides a mechanical force to the corrector lens assembly in the focusing direction.

Thus, according the invention, an axially compact actuation system (i.e., in the direction of the optical axis OA) is provided for the lens actuator assembly, 15 in which the first actuator and the second actuator, or at least a part of each actuator, are substantially at the same axial position or location along the optical axis. In other words, there is at least some overlapping, and preferably full overlapping, in the optical axis direction, of the first and second actuators, i.e., of the coils themselves and/or of the magnet arrangements used therewith. This is 20 the case for the embodiments discussed above in which a common magnet assembly or arrangement is used in conjunction with the actuators used in the focusing direction, and also for embodiments in which separate magnets are used for the height control and focusing actuators. Thus, the magnet arrangement used for the first actuator may be separate from the magnet arrangement used for the 25 second actuator for actuating in the focusing direction, and moreover, the two magnet arrangements may be angularly displaced one from the other when viewed along the optical axis. For example, in some of the exemplary embodiments disclosed above; the two magnet arrangements are orthogonally arranged with respect to the optical axis. Nevertheless, any other arrangement 30 may be provided.

In yet other embodiments, the main lens holder for the objective lens may comprise focusing coils in the focus/tangential plane, as well as in the focus/tracking plane, or indeed any combinations or orientations of planes, and

5 indeed the coils may also be provided on a coil board that is curved or non-planar in any suitable manner, for example cylindrical having the center of curvature along the optical axis **OA**, and a suitable magnet arrangement is provided for actuating the same.

Additionally or alternatively, the lens holder for the corrector lens may

10 comprise height control coils in the focus/tangential plane, as well as in the focus/tracking plane, or indeed any combinations or orientations of planes, and indeed the coils may also be provided on a coil board that is curved or non-planar in any suitable manner, for example cylindrical having the center of curvature along the optical axis **OA**, and a suitable magnet arrangement is provided for

15 actuating the same.

It should be noted that the word "comprising" as used throughout the appended claims is to be interpreted to mean "including but not limited to".

20 While there has been shown and disclosed exemplary embodiments in accordance with the invention, it will be appreciated that many changes may be made therein without departing from the spirit of the invention.